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“Total Mass Accounting in Advanced Liquid-Fueled Reactors”

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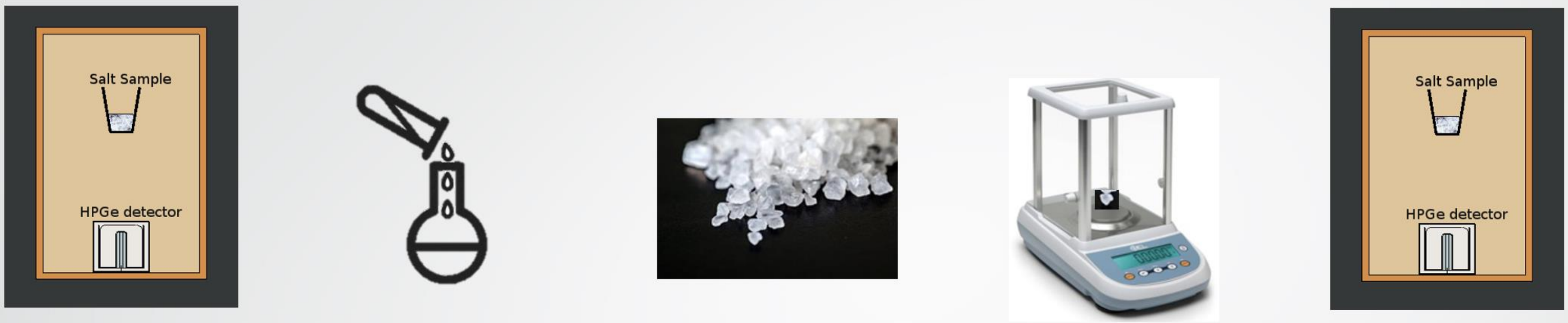
ARS Spring Working Group Meeting, Sandia National Lab, May 3rd 2022

Objectives

The objective of this research is to validate a radioactive tracer dilution (RTD) method for the irradiated fuel-bearing molten salt mass determination to evaluate the possibilities of its deployment in NMA scenarios, e.g., in molten salt loop in LFMSRs.

The principle of RTD



Measure Activity (A1) → **Spike** → **Sample** → **Weigh (m)** → **Measure Activity (A2)**

- **Measure Activity (A1)**
  - Measure activity of Na-22 Salt (tracer)
- **Spike**
  - Add Na-22 Tracer to the salt of TBD
- **Sample**
  - Sampling
- **Weigh (m)**
  - Weigh the mass of the sample
- **Measure Activity (A2)**
  - Measure activity of the sample

$$\boxed{Mass_{tot} = \left(\frac{A_1}{A_2}\right) * m_{sample}}$$

Radioactive tracer selection:

^{22}Na was selected as the first radioactive tracer to test the RTD concept because –

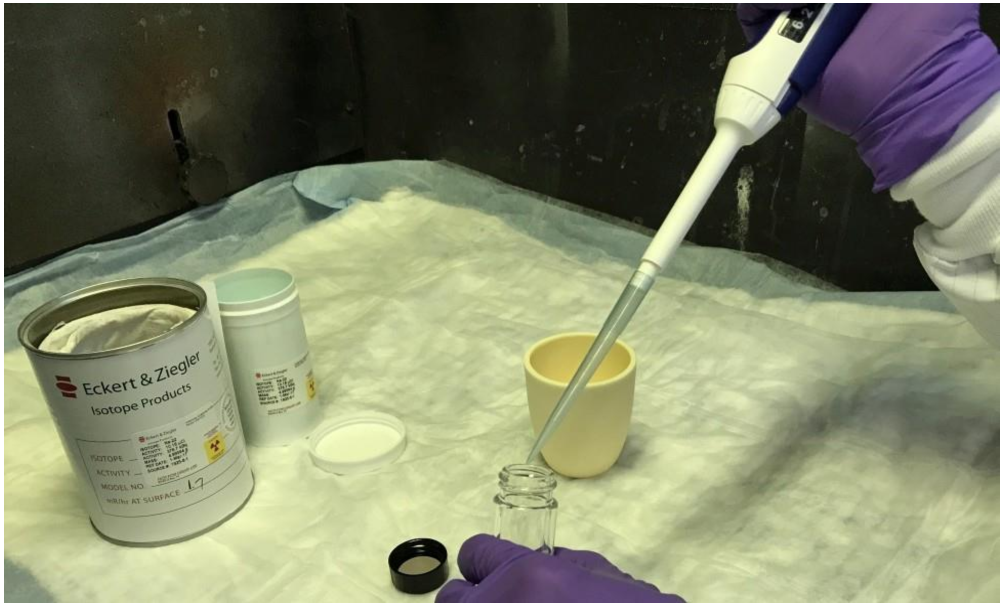
- It undergoes beta+ decay (non-fission product characteristic)
- known chemical compatibility with actinides and fission products in molten chloride and fluoride salts
- Availability and the half life (2.6y) for handling
- Emits 1274.54 keV gamma-ray (99.94%), high enough to be outside of the Compton plateau of many fission products' gamma-rays in a gamma energy spectrum
- Identified overlapped peak at 1274.43 keV from ^{154}Eu

Experimental Method (2017-2018)

Step 1
- Add Tracers to Empty Crucible
  - 1.29 µCi Na-22
  - 3.1 µCi Eu-154
  - 10.06 µCi Cs-137

Step 2
- Add LiCl-KCl Salt to crucible and melt to form one solid piece

Step 3
- Measure Activity of Tracer+ Salt solid



Prior work: Proof-of-concept with the clean salt (contd.)

Step 4
- Re-melt, solidify, and partition salt into separate crucibles

Step 5
- Re-melt, re-solidify each of crucibles

Step 6
- Measure activity of Tracer+ Salt in separate crucibles

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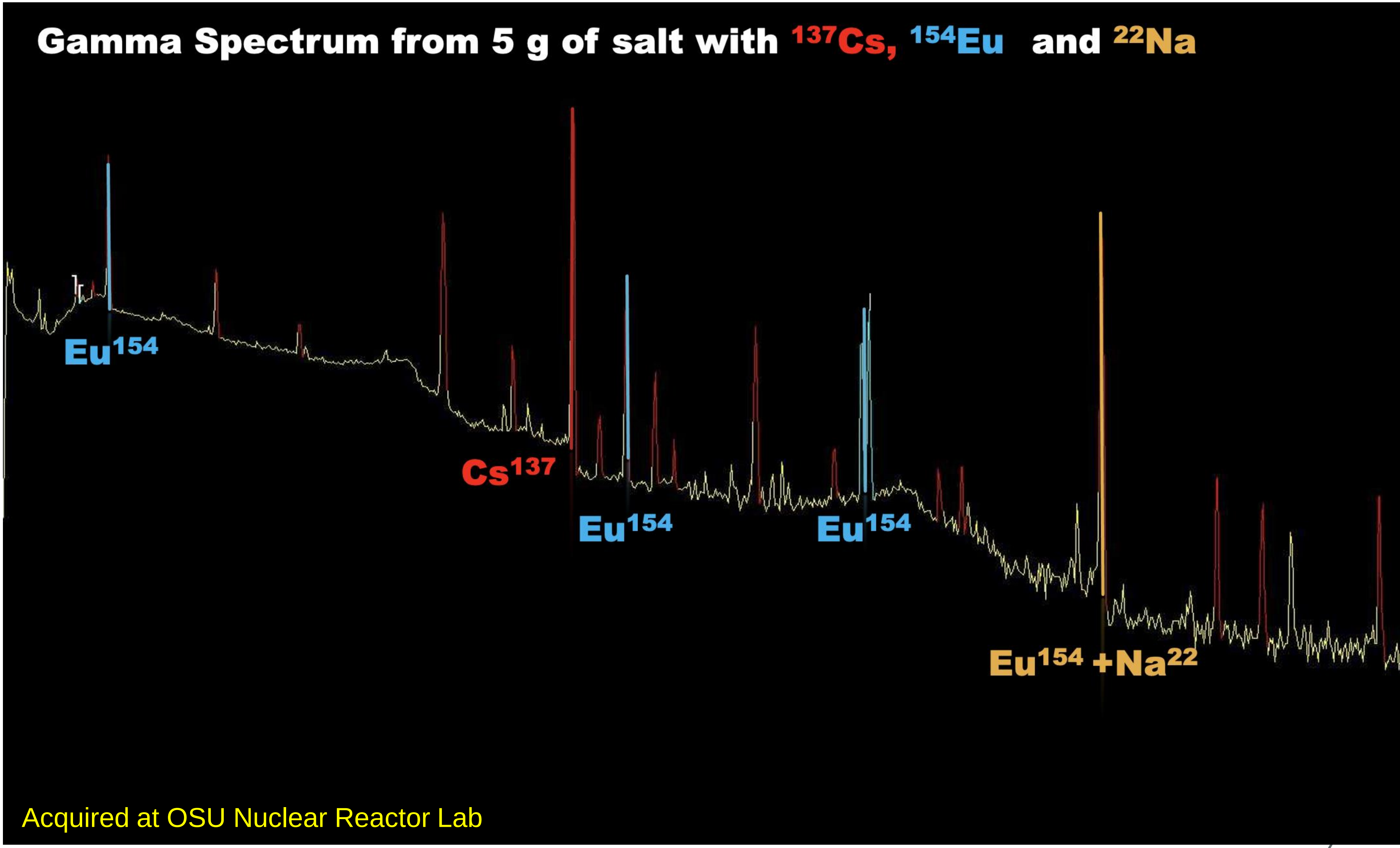
Gamma Spectroscopy



Challenges: Off-gas Constituents

Table 1
Potential species in the cover gas of an MSR.

Type of cover gas constituent	Example species
Mists, aerosols, and particles	Salt residues, graphite debris for graphite-moderated fluoride systems, corrosion products, and noble metals (e.g., Ru, Pd, Rh)
Gases and volatile species	^{3}HF, HF, F_2, Cl_2, Br_2, I_2, Ar, interhalogens (e.g., ICl, IF_5, IF_7), volatile halides, and the decay products (e.g., Cs, Ba, Rb, Sr, La, Br, I, Se, Te) (Ostvald et al., 2009)
Tritium	$^{3}H_{2(g)}$, $^{3}HH_{(g)}$, $^{3}HF_{(g)}$, $^{3}HF_{(l)}$, and possibly $^{3}HHO_{(g)}$ and/or $^{3}H_2O_{(g)}$
Short-lived fission gases and their daughters	^{139}Xe $t_{½} = 39.5$ s, ^{137}Xe $t_{½} = 3.83$ min, ^{135m}Xe $t_{½} = 15.3$ min, ^{135}Xe $t_{½} = 9.1$ h, ^{133m}Xe $t_{½} = 2.19$ d, ^{133}Xe $t_{½} = 5.25$ d, ^{90}Kr $t_{½} = 32.3$ s, ^{89}Kr $t_{½} = 3.18$ min, ^{88}Kr $t_{½} = 2.84$ h
Longer-lived radionuclides	^{129}I $t_{½} = 1.57 \times 10^{7}$ y, ^{79}Se $t_{½} = 6.5 \times 10^{4}$y, ^{85}Kr $t_{½} = 10.7$ y, ^{36}Cl $t_{½} = 3 \times 10^{5}$ y

Source: *Andrews, Hunter et al. "Review of molten salt reactor off-gas management considerations." Nuclear Engineering and Design **385** (2021): 111529.*

Fission Product Activities

- Estimated fission products activities from spreadsheet calculations
- Serpent and MCNP–ORIGEN are being requested from RSICC

INPUT PARAMETERS		
		Description
φ_{th} ($cm^{-2}.s^{-1}$)	1E+13	Thermal Neutron Flux in CIF
m_{U235} (g)	0.01	mass of U-235
t_{irr}(h)	1	irradiation time
t_d (h)	24	decay time after irradiation
$A_{Na22,0}$ (Ci)	1.00E-03	initial ^{22}Na Activity

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Fission Product Activity Decay Time: 10 h

	Fission product, half-life, main gamma energy	Fission Product Activity (μCi) at t_{irr} + t (t = 0)	at t_{irr} + t (t = t_d); see B9 for t_d
	^{137}Cs; 30.07 years; 662 keV	6.65	6.65
	^{154}Eu; 8.59 years; 1274 keV, 723 keV, 123 keV	0.00	0.00
	^{155}Eu; 4.76 years; 86.5 keV, 105.3 keV	0.21	0.21
Krypton	^{85}Kr; 10.7 y; 514 keV	0.86	0.86
	^{85m}Kr; 4.48 h; 151 keV	7.59E+04	1.62E+04
	^{88}Kr; 2.84 h; 2392 keV	3.14E+05	2.73E+04
	^{89}Kr; 3.15 min; 221 keV	1.87E+06	0.00
	^{90}Kr; 32.32 s; 1118.7 keV	2.05E+06	0.00E+00
Iodine	^{129}I; 1.57×10^7 y; 39.578 keV	0.00	0.00
	^{131}I; 8 days; 364 keV	4.20E+03	4.05E+03
	^{133}I; 20.8 h; 530 keV	8.77E+04	6.29E+04
	^{135}I; 6.57 h; 1260 keV, 1132 keV	2.60E+05	9.05E+04
Xenon	^{131m}Xe; 11.934 d; 163.93 keV	30.74	3.00E+01
	^{133}Xe; 5.25 d; 81 keV	1.47E+04	1.39E+04
	^{133m}Xe; 2.19 d;	1.01E+03	8.82E+02
	^{135}Xe; 9.14 h; 250 keV	1.96E+05	9.19E+04
	^{135m}Xe; 15.3 min; 250 keV	4.63E+05	7.25E-07
	^{137}Xe; 3.818 min; keV	2.48E+06	0.00
	^{139}Xe; 39.68 s; 218.59 keV	2.09E+06	0.00
	^{90}Sr; 28.8 years	6.40	6.40E+00
	^{95}Zr; 64 days; 724 keV, 757 keV	1.19E+03	1.19E+03
	^{95}Nb; 35 days; 766 keV	2.18E+03	2.16E+03
	TOTAL ACTIVITY (μCi)	**9.91E+06**	**3.11E+05**

Fission Product Activity Decay Time: 100 h

	Fission Product Activity (μCi)		
	Fission product, half-life, main gamma energy	at t_{irr} + t (t = 0)	at t_{irr} + t (t = t_d); see B9 for t_d
	^{137}Cs; 30.07 years; 662 keV	6.65	6.65
	^{154}Eu; 8.59 years; 1274 keV, 723 keV, 123 keV	0.00	0.00
	^{155}Eu; 4.76 years; 86.5 keV, 105.3 keV	0.21	0.21
Krypton	^{85}Kr; 10.7 y; 514 keV	0.86	0.86
	^{85m}Kr; 4.48 h; 151 keV	7.59E+04	1.45E-02
	^{88}Kr; 2.84 h; 2392 keV	3.14E+05	7.89E-06
	^{89}Kr; 3.15 min; 221 keV	1.87E+06	0.00
	^{90}Kr; 32.32 s; 1118.7 keV	2.05E+06	0.00E+00
Iodine	^{129}I; 1.57×10^7 y; 39.578 keV	0.00	0.00
	^{131}I; 8 days; 364 keV	4.20E+03	2.93E+03
	^{133}I; 20.8 h; 530 keV	8.77E+04	3.13E+03
	^{135}I; 6.57 h; 1260 keV, 1132 keV	2.60E+05	6.81E+00
Xenon	^{131m}Xe; 11.934 d; 163.93 keV	30.74	2.41E+01
	^{133}Xe; 5.25 d; 81 keV	1.47E+04	8.49E+03
	^{133m}Xe; 2.19 d;	1.01E+03	2.69E+02
	^{135}Xe; 9.14 h; 250 keV	1.96E+05	9.98E+01
	^{135m}Xe; 15.3 min; 250 keV	4.63E+05	4.12E-113
	^{137}Xe; 3.818 min; keV	2.48E+06	0.00
	^{139}Xe; 39.68 s; 218.59 keV	2.09E+06	0.00
	^{90}Sr; 28.8 years	6.40	6.40E+00
	^{95}Zr; 64 days; 724 keV, 757 keV	1.19E+03	1.14E+03
	^{95}Nb; 35 days; 766 keV	2.18E+03	2.01E+03
	TOTAL ACTIVITY (μCi)	**9.91E+06**	**1.81E+04**

Fission Product Activity Decay Time: 3 months

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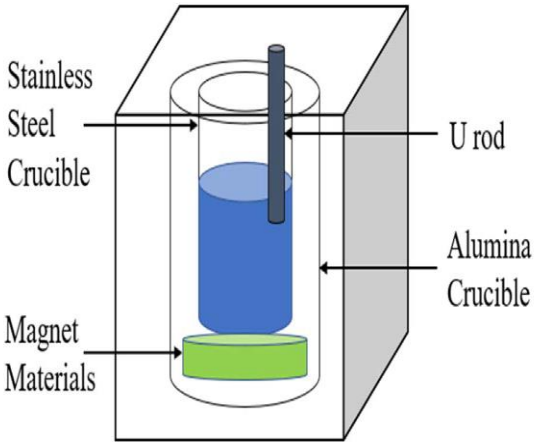
	Fission product, half-life, main gamma energy	Fission Product Activity (μCi) at t_{irr} + t (t = 0)	at t_{irr} + t (t = t_d); see B9 for t_d
	^{137}Cs; 30.07 years; 662 keV	6.65	6.61
	^{154}Eu; 8.59 years; 1274 keV, 723 keV, 123 keV	0.00	0.00
	^{155}Eu; 4.76 years; 86.5 keV, 105.3 keV	0.21	0.20
Krypton	^{85}Kr; 10.7 y; 514 keV	0.86	0.84
	^{85m}Kr; 4.48 h; 151 keV	7.59E+04	0.00
	^{88}Kr; 2.84 h; 2392 keV	3.14E+05	0.00
	^{89}Kr; 3.15 min; 221 keV	1.87E+06	0.00
	^{90}Kr; 32.32 s; 1118.7 keV	2.05E+06	0.00
Iodine	^{129}I; 1.57×10^7 y; 39.578 keV	0.00	0.00
	^{131}I; 8 days; 364 keV	4.20E+03	1.58E+00
	^{133}I; 20.8 h; 530 keV	8.77E+04	0.00
	^{135}I; 6.57 h; 1260 keV, 1132 keV	2.60E+05	0.00
Xenon	^{131m}Xe; 11.934 d; 163.93 keV	30.74	1.53E-01
	^{133}Xe; 5.25 d; 81 keV	1.47E+04	8.62E-02
	^{133m}Xe; 2.19 d;	1.01E+03	0.00
	^{135}Xe; 9.14 h; 250 keV	1.96E+05	0.00
	^{135m}Xe; 15.3 min; 250 keV	4.63E+05	0.00
	^{137}Xe; 3.818 min; keV	2.48E+06	0.00
	^{139}Xe; 39.68 s; 218.59 keV	2.09E+06	0.00
	^{90}Sr; 28.8 years	6.40	6.36E+00
	^{95}Zr; 64 days; 724 keV, 757 keV	1.19E+03	4.44E+02
	^{95}Nb; 35 days; 766 keV	2.18E+03	3.57E+02
	TOTAL ACTIVITY (μCi)	**9.91E+06**	**8.17E+02**

Acquisition of fuel salt and radioactive tracer

Preparation of NaCl-KCl-UCl_3 salt for irradiation (UoU)

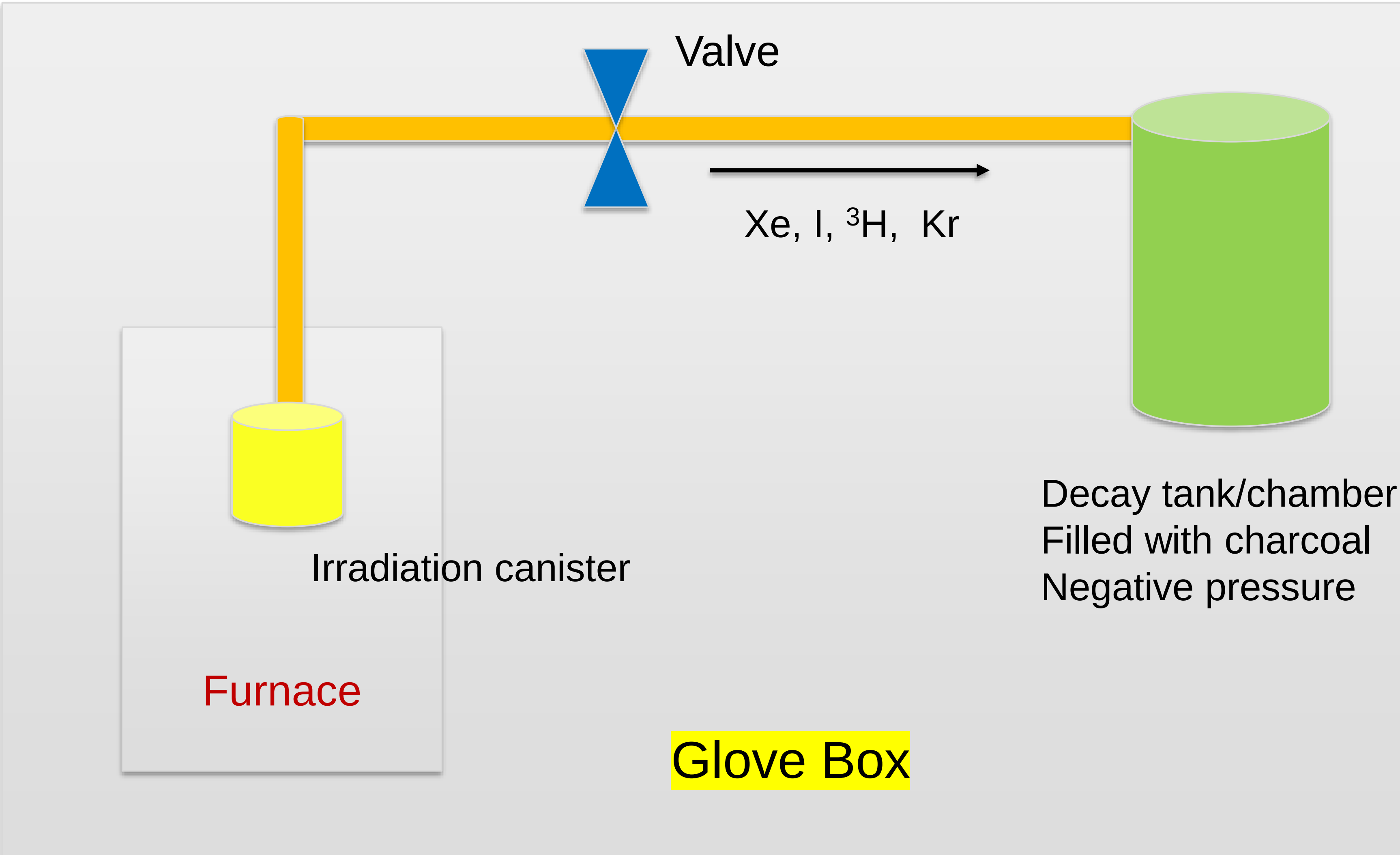
- 13.8 g of $MgCl_2$-KCl-UCl_3 (DU) fuel salt has been prepared at Nuclear PyroMetallurgy Laboratory, the University of Utah
- High purity (99.99%) $MgCl_2$ and KCl was acquired through commercial vendors and mixed with a 1:1 molar ratio.
- UCl_3 was synthesized by using DU metal rod and $FeCl_2$ in $MgCl_2$-KCl at ~700°C.Salt samples were taken and measured by ICP-MS, the UCl_3 concentration was determined to be 15.15 wt%. The $FeCl_2$ concentration is 0.045 wt%.
- U-235 concentration is …. TBD
- $MgCl_2$-KCl-UCl_3 salt will be packed in an argon glovebox and shipped to OSU by a commercial carrier



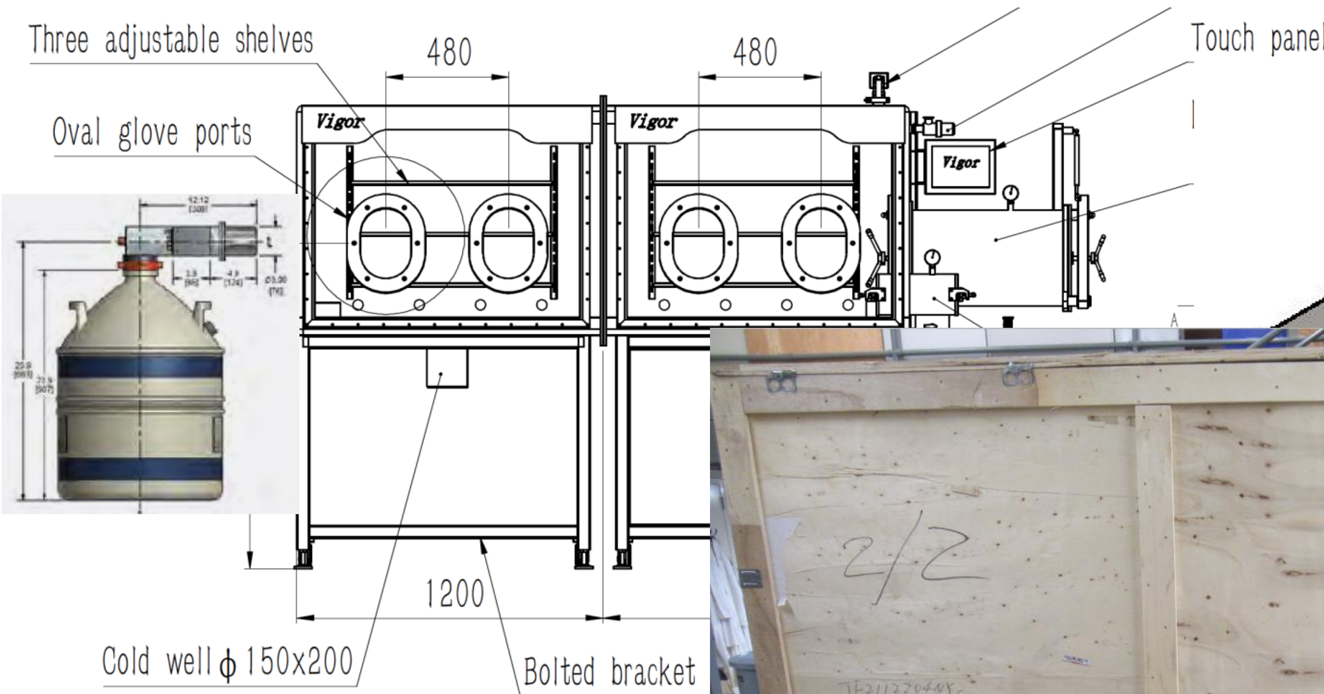
Schematic for preparing UCl_3 salt from DU metal rod and NaCl-KCl-$FeCl_2$

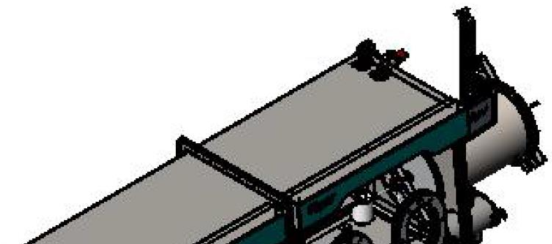
Huan Zhang et al 2021, J. Electrochem. Soc. 168 056521

Irradiated salt process and measurement plan



Order placed for a customized glovebox



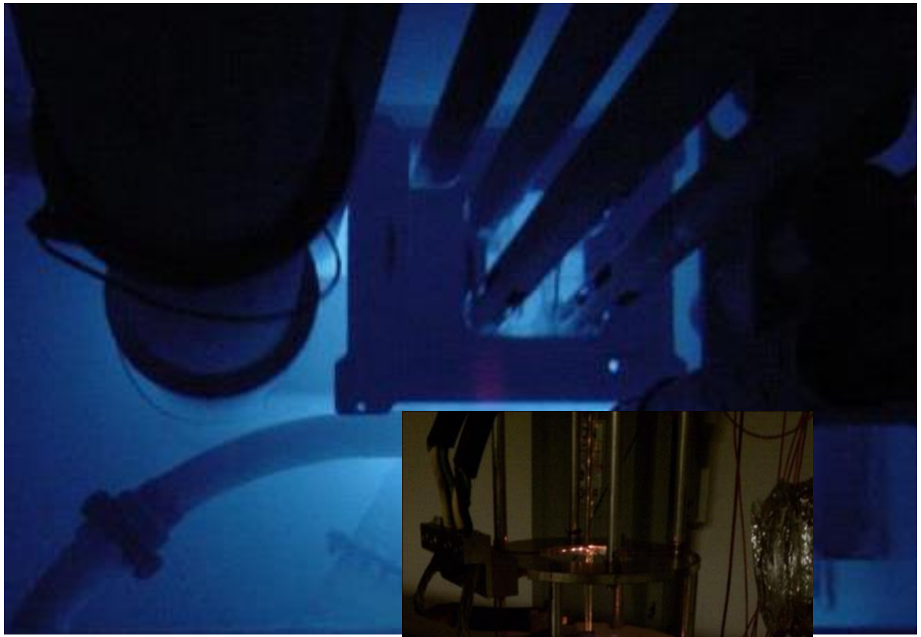


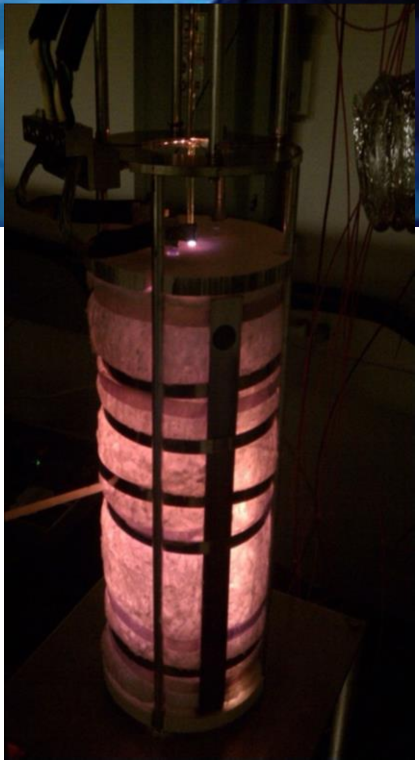
1. Rounded corners(R20). Polished internal walls f
2. Patented leak-free double vacuum seals. Ultra
3. Four Oval glove ports.
4. Eight standard feedthroughs on back wall seal
5. Cold well with cover.
6. DN100 flange, centered on the left panel.

Experimental Approach

Phase 1 Experiment:

- Prepare UCl_3+MgCl2+KCl with DU, ~ mg of U-235,
- Add ^{22}NaCl tracer
- Melted and sealed in irradiation cell
- Irradiate at OSU Research Reactor for 2 hours
- Decay
- Survey the activity and measure the gamma-spectrum (without opening the container)





Estimated Dose Rates for 10 grams of Fuel Salt Mixture:
4 g MgCl2, 4 g KCl, and 2 g UCl3

Irradiation Facility: CIF
Flux: 1.6x 10^{13} n/cm^2/s
Thermal to Fast ratio: 1.4545
Irradiation time: 1 hour

Isotope	Mass (grams)	Distance from source	Time to Decay (after 1 hour irradiation)	Gamma Dose rate (mrem/hr)	Beta Dose rate (mrem/hr)	Total Dose rate (mrem/hr)
Na-24	1.021	1 meter	64 hours	4.18E-02	6.01E-01	6.43E-01
K-42	2.098			2.78E-01	5.41E+01	5.44E+01
S-35 (from Cl)	5.498			0.00E+00	1.52E+02	1.52E+02
P-32 (from Cl)				0.00E+00	9.27E-01	9.27E-01
Na-24	1.021	10 cm	64 hours	4.18E+00	6.01E+01	6.43E+01
K-42	2.098			2.78E+01	5.41E+03	5.44E+03
S-35 (from Cl)	5.498			0.00E+00	1.52E+04	1.52E+04
P-32 (from Cl)				0.00E+00	9.27E+01	9.27E+01
Na-24	1.021	1 meter	7 days	3.41E-04	4.91E-03	5.25E-03
K-42	2.098			8.00E-04	1.56E-01	1.57E-01
S-35 (from Cl)	5.498			0.00E+00	1.47E+02	1.47E+02
P-32 (from Cl)				0.00E+00	7.51E-01	7.51E-01
Na-24	1.021	10 cm	7 days	3.41E-02	4.91E-01	5.25E-01
K-42	2.098			8.00E-02	1.56E+01	1.57E+01
S-35 (from Cl)	5.498			0.00E+00	1.47E+04	1.47E+04
P-32 (from Cl)				0.00E+00	7.51E+01	7.51E+01

Isotope	Mass (grams)	Distance from source	Time to Decay (after 1 hour irradiation)	Gamma Dose rate (mrem/hr)	Beta Dose rate (mrem/hr)	Total Dose rate (mrem/hr)
Cs-137	10 mg U-235	30 cm	64 hours	2.84E-03	2.08E-01	2.10E-01
Eu-154				0.00E+00	0.00E+00	0.00E+00
Eu-155				1.48E-05	6.19E-03	6.20E-03
Kr-85				1.57E-06	2.79E-02	2.79E-02
Kr-85m				6.78E-04	1.18E-01	1.19E-01
Kr-88				5.43E-05	1.48E-03	1.53E-03
Kr-89				0.00E+00	0.00E+00	0.00E+00
Kr-90				0.00E+00	0.00E+00	0.00E+00
I-133				1.06E+01	7.22E+02	7.33E+02
I-131				2.19E+01	2.16E+03	2.18E+03
I-135				1.04E-03	3.36E-02	3.46E-02
Xe-133				1.18E+00	3.20E+02	3.21E+02
Xe-135				3.22E-01	4.74E+01	4.78E+01
Xe-135m				4.30E-74	3.74E-72	3.79E-72
Xe-137				6.99E-301	1.57E-298	1.58E-298
Xe-139				N/A	0.00E+00	N/A
Sm-149				N/A	0.00E+00	N/A
Sr-90				N/A	3.69E+01	N/A
Zr-95				5.98E-01	3.58E+01	3.64E+01
Nb-95				1.10E+00	6.41E+01	6.52E+01
Se-79				#N/A	0.00E+00	#N/A
			Total Dose	**3.57E+01**	**3.39E+03**	**3.38E+03**

Cs-137	10 mg U-235	10 cm	64 hours	2.56E-02	1.87E+00	1.89E+00
Eu-154				0.00E+00	0.00E+00	0.00E+00
Eu-155				1.33E-04	5.57E-02	5.58E-02
Kr-85				1.41E-05	2.51E-01	2.51E-01
Kr-85m				6.10E-03	1.06E+00	1.07E+00
Kr-88				4.89E-04	1.33E-02	1.38E-02
Kr-89				0.00E+00	0.00E+00	0.00E+00
Kr-90				0.00E+00	0.00E+00	0.00E+00
I-133				9.53E+01	6.50E+03	6.60E+03
I-131				1.97E+02	1.94E+04	1.96E+04
I-135				9.33E-03	3.02E-01	3.11E-01
Xe-133				1.06E+01	2.88E+03	2.89E+03
Xe-135				2.90E+00	4.27E+02	4.30E+02
Xe-135m				3.87E-73	3.37E-71	3.41E-71
Xe-137				6.29E-300	1.42E-297	1.42E-297
Xe-139				N/A	0.00E+00	N/A
Sm-149				N/A	0.00E+00	N/A
Sr-90				N/A	3.32E+02	N/A
Zr-95				5.38E+00	3.22E+02	3.28E+02
Nb-95				9.93E+00	5.77E+02	5.87E+02
Se-79				N/A	0.00E+00	N/A
			Total Dose	**3.21E+02**	**3.05E+04**	**3.05E+04**

Estimated Dose Rates for 3 grams of Fuel Salt Mixture:

1 g MgCl2, 1 g KCl, and 1 g UCl3

Irradiation Facility: CIF
Flux: 1.6x 10^{13} n/cm^2/s
Thermal to Fast ratio: 1.4545
Irradiation time: 1 hour

Isotope	Mass (grams)	Distance from source	Time to Decay (after 1 hour irradiation)	Gamma Dose rate (mrem/hr)	Beta Dose rate (mrem/hr)	Total Dose rate (mrem/hr)
Na-24	0.3934	1 meter	64 hours	1.05E-02	1.51E-01	1.61E-01
K-42	0.5244			6.95E-02	1.35E+01	1.36E+01
S-35 (from Cl)	1.0822			0.00E+00	4.23E+01	4.23E+01
P-32 (from Cl)				0.00E+00	2.62E+00	2.62E+00
Na-24	0.3934	10 cm	64 hours	1.05E+00	1.51E+01	1.61E+01
K-42	0.5244			6.95E+00	1.35E+03	1.36E+03
S-35 (from Cl)	1.0822			0.00E+00	4.23E+03	4.23E+03
P-32 (from Cl)				0.00E+00	2.62E+02	2.62E+02
Na-24	0.3934	1 meter	7 days	8.56E-05	1.23E-03	1.32E-03
K-42	0.5244			2.00E-04	3.89E-02	3.91E-02
S-35 (from Cl)	1.0822			0.00E+00	4.09E+01	4.09E+01
P-32 (from Cl)				0.00E+00	2.12E+00	2.12E+00
Na-24	0.3934	10 cm	7 days	8.56E-03	1.23E-01	1.32E-01
K-42	0.5244			2.00E-02	3.89E+00	3.91E+00
S-35 (from Cl)	1.0822			0.00E+00	4.09E+03	4.09E+03
P-32 (from Cl)				0.00E+00	2.12E+02	2.12E+02

Isotope	Mass (grams)	Distance from source	Time to Decay (after 1 hour irradiation)	Gamma Dose rate (mrem/hr)	Beta Dose rate (mrem/hr)	Total Dose rate (mrem/hr)
Cs-137	1.4 mg U-235	30 cm	64 hours	3.82E-04	2.79E-02	2.83E-02
Eu-154				0.00E+00	0.00E+00	0.00E+00
Eu-155				0.00E+00	0.00E+00	0.00E+00
Kr-85				1.74E-07	3.10E-03	3.10E-03
Kr-85m				9.47E-05	1.65E-02	1.66E-02
Kr-88				7.59E-06	2.07E-04	2.14E-04
Kr-89				0.00E+00	0.00E+00	0.00E+00
Kr-90				0.00E+00	0.00E+00	0.00E+00
I-133				6.65E-01	4.53E+01	4.60E+01
I-131				1.47E-01	1.45E+01	1.46E+01
I-135				1.45E-04	4.70E-03	4.84E-03
Xe-133				1.66E-01	4.49E+01	4.50E+01
Xe-135				4.52E-02	6.65E+00	6.70E+00
Xe-135m				6.01E-75	5.24E-73	5.30E-73
Xe-137				9.80E-302	2.21E-299	2.22E-299
Xe-139				N/A	0.00E+00	N/A
Sm-149				N/A	0.00E+00	N/A
Sr-90				N/A	2.79E-02	N/A
Zr-95				5.98E-01	3.58E+01	3.64E+01
Nb-95				1.54E-01	8.96E+00	9.12E+00
Se-79				N/A	0.00E+00	N/A
			Total Dose	**1.78E+00**	1.56E+02	1.58E+02

Cs-137	1.4 mg U-235	10 cm	64 hours	0.00E+00	0.00E+00	0.00E+00
Eu-154				0.00E+00	0.00E+00	0.00E+00
Eu-155				5.98E+00	4.08E+02	4.14E+02
Kr-85				1.32E+00	1.30E+02	1.32E+02
Kr-85m				1.31E-03	4.23E-02	4.36E-02
Kr-88				1.49E+00	4.04E+02	4.05E+02
Kr-89				4.07E-01	5.99E+01	6.03E+01
Kr-90				5.41E-74	4.71E-72	4.77E-72
I-133				8.82E-301	1.99E-298	2.00E-298
I-131				N/A	0.00E+00	N/A
I-135				N/A	0.00E+00	N/A
Xe-133				N/A	2.51E-01	N/A
Xe-135				5.38E+00	3.22E+02	3.28E+02
Xe-135m				1.39E+00	8.07E+01	8.21E+01
Xe-137				N/A	0.00E+00	N/A
Xe-139				0.00E+00	0.00E+00	0.00E+00
Sm-149				0.00E+00	0.00E+00	0.00E+00
Sr-90				5.98E+00	4.08E+02	4.14E+02
Zr-95				1.32E+00	1.30E+02	1.32E+02
Nb-95				1.31E-03	4.23E-02	4.36E-02
Se-79				1.49E+00	4.04E+02	4.05E+02
			Total Dose	**1.60E+01**	1.41E+03	1.42E+03

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Sample Preparation for Irradiation

Sample Vial – 20 mm (10 mL capacity)

Quartz (Fused Silica)
Aluminum Foil
Aluminum Crimp Cap
Grafoil gasket

External Containment Vessel (70 mL capacity)

Aluminum Body (Al-1100)
Grafoil gasket

** Quartz containment vessel
available smaller samples

Sample Preparation for Irradiation

Aluminum Crimp Seals

11 mm Solid Cap

*Max Pressure: 40-55 psi
Max Temp: 550 C

*Pressure increase of 1 mL (4e-5 moles) of argon due to temperature rise from 20°C to 150°C during irradiation estimated to be 21 psi (~1.4 atm) or less.

Based on ideal Gas law: PV=nRT

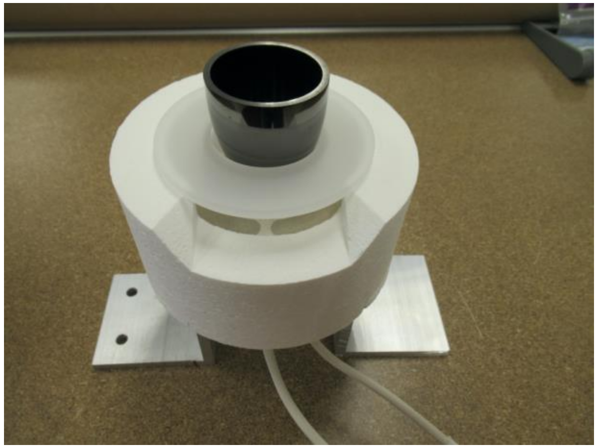
Gaskets

- **MicaTherm**
  - Max Temp: 900 C (in Oxygen)
- **Flexible Graphite**
  - Max Temperature: 450 C (in Oxygen)
    2980 C (in Argon)
  - Max Pressure: 1450-2900 psi

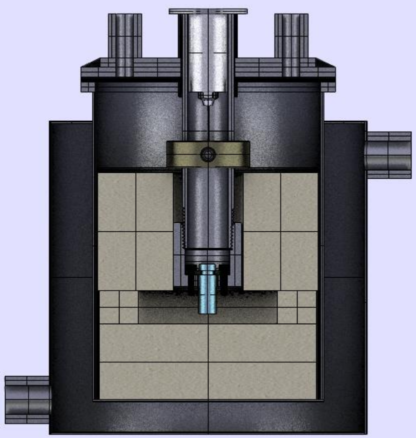
Containment System for Heating and Off-gassing

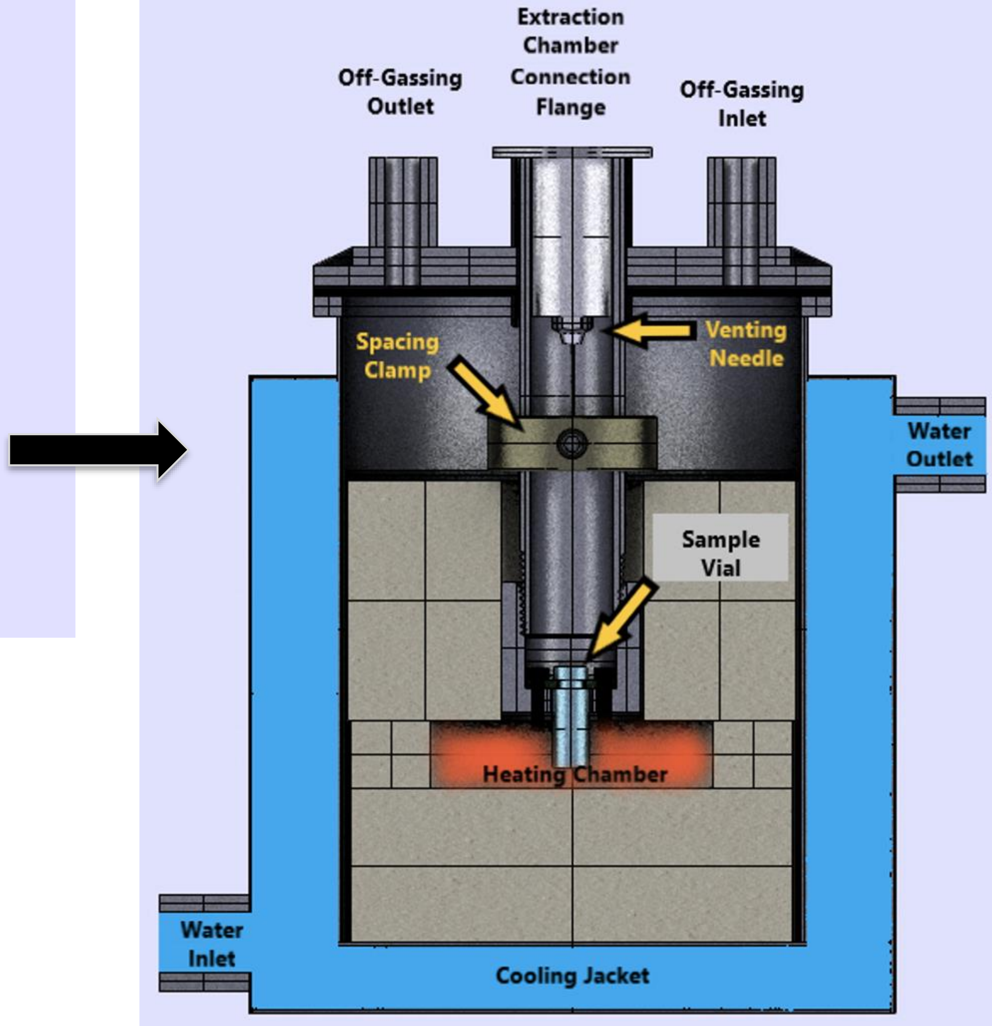
Ultralite Kiln – (Modified in-house) with glassy carbon crucible

Containment vessel (6” I.D. x 8” Tall) with cooling Jacket



Containment System for Heating and Off-gassing





Heating Element:
Ultralite kiln capable of reaching 850°C

Sample Vial:
Fused Silica glass 2 mL / 20 mL capacity

Mass of Sample:
$MgCl_2$, KCl, and UCl_3 = 3-20 g total

Acknowledgments

NEUP Nuclear Energy University Programs
U.S. Department of Energy


Praneeth Kandlakunta


Matt Van Zile


Andrew Kauffman

THE UNIVERSITY OF UTAH


Mike Simpson


Shelly Li


Emily Gordon


Raymond Cao

Thanks to Dr. Shayan Shahbazi, Dr. Tingzhou Fei at ANL for help with burn-up simulation

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Thank you for your attention!

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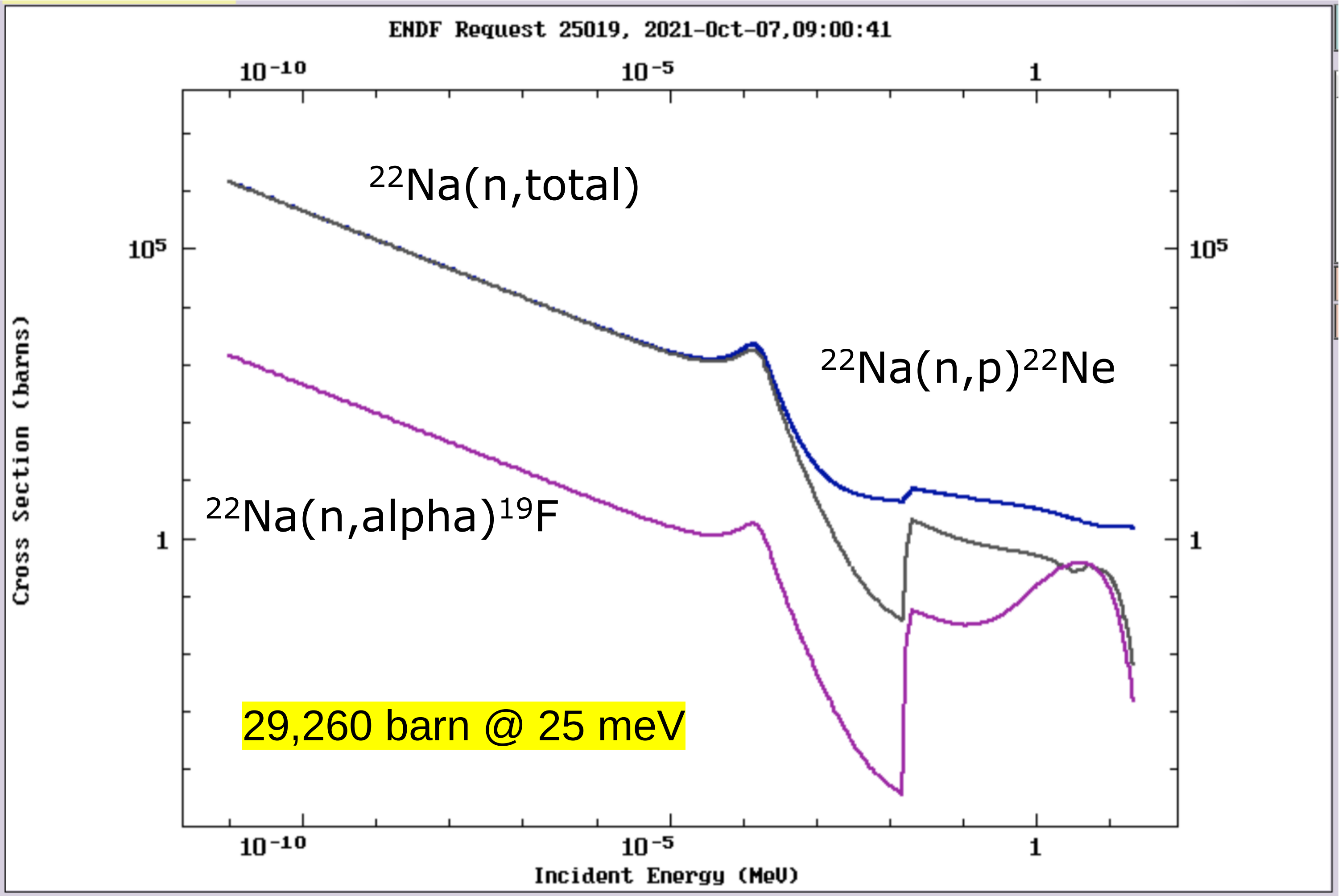
Challenges with tracer burn-up

- Na-22 has a significant neutron absorption cross-section



https://www.nndc.bnl.gov/

Radioisotope Selection

Two or more gamma lines in one isotope might be used to verify each other or in case one has an interference

May add two isotopes to validate each other or in case one has an interference

Na-22 is the best option

	Na-22	Co-60	Na-24	Br-82
Decay mode	β+	β-	β-	β-
Main gamma energy/keV	1274.54	1173.23; 1332.50	1368.63; 2754.01	554.35; 619; 776.52;1044
Half life	2.6018 y	1925 d	14.977 h	35.28 h
Comments	Not a fission product	Selective bounding?	$T_{1/2}$ too short	$T_{1/2}$ too short

Collaboration with Dr. Shayan Shahbazi, Dr. Tingzhou Fei at ANL for burn-up simulation

20 grams of UCl3 + KCl + $MgCl_2$
10% - 20% of U
2-4 grams of U
0.3% U-235 in DU
6 mg - 12 mg of U-235
Total volume of 2.0 cm^3

φ_{th} ($cm^{-2}.s^{-1}$)	1E+13	Thermal Neutron Flux in CIF
m_{U235} (g)	0.1	mass of U-235 in grams
t_{irr}(h)	1	irradiation time in hours

^{133}Xe; 5.25 d; 81 keV

Yield of ^{133}Xe at t=0, 14,700 uCi. 3.5E20 atoms